Talk
William Carey Lecture
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# BEHIND THE ENDLESS FRONTIER

Vannever Bush's 50 year old paradigm for the organization of scientific research and training is now being debated. Is it still pertinent? Will it survive? In a rapidly evolving world, it is always important to examine standing policies and ask whether they are optimal for the new and coming times. But whatever the outcome of those policy debates, we should recognize that Bush provided an enduring metaphor for science itself: The Endless Frontier.

Implied by that metaphor is a frontier space, and a border that separates the frontier from the space behind. That place behind the endless frontier, like the regions behind geographical frontiers, is filled with people whose perspectives are vastly different from those prevailing within the frontier community.

A lot of scientists like to ignore the place behind the frontier. Some, perhaps a diminishing group, ignore it through arrogance. Others are too busy with the latest findings, the newest methods, meetings, grant applications, and teaching to take the time to look; there is a sense in which working scientists use all these activities as a haven to insulate themselves not only from issues outside the scientific community, but even from some of the troubles within it, much as the vast western spaces provided a haven for19th century frontier people. Of course, dark threatening clouds moving in science's direction from behind the frontier attract attention, as is currently the case. So, perhaps this is a propitious time to try to understand the relation between the frontier and the complex currents moving behind it.

There is, of course, a long list of such currents, and ~~many~~ some of them are the subject of presentations and discussions during this Colloquium on Science and Technology Policy. From this that last observation you will realize that I place the science policy community, so fully represented on your program by distinguished and thoughtful people, in the space behind the frontier; to be sure, closer to the border than many other important constituencies, but behind nevertheless. The palpable border between science itself and the policy and politics of science is evident in the preliminary program for this meeting. No time was scheduled for presentations on the latest scientific news from especially fast moving research areas. Are the actual scientific advances not relevant to the making of policy? Shouldn't working scientists be heard in this forum — talking about the directions of their fields? In this meeting on Science and Technology Policy, only one speaker is ~~even~~ scheduled to talk about "A Researcher's View of the Issues"., let alone the science itself. Moreover, as late as the distribution of a preliminary program 10 days ago, this ~~is~~ was the only slot on the program that has a phantom speaker: ~~the version of~~ the program I

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the program says

~~received says~~ 'speaker to be announced'. The unfortunate habit of ignoring the other side of the frontier is apparently not unique to research scientists.

This observation is a good starting place for what it is I want to talk about: the way science is communicated to those further back behind the frontier...communicated by working scientists and teachers and by your own science policy community.

There is a major discontinuity between scientists' views of the natural world and those held even by relatively well-educated segments of the nonscientific public. Vocuabulary is part of the problem; the words of science increase geometrically with new discoveries. But even putting vocabulary problems aside, there are basic conceptual diffferences that plague scientists' efforts to share the implications of their exciting new findings with the public in a constructive manner. Recognizing this discontinuity, many scientists are becoming involved in K-12 science education. By engaging in science teaching at the level of the classroom, scientists are beginning to learn why communication with the childrens' parents and thus the rest of the community behind the frontier is so difficult. To give you a well-known example, many people don't know the difference between astrology and astronomy, or even that there is a difference.

At the same time, scientists hope that by these educational efforts the general public of the future will have an improved understanding of science and the nature of its findings, and thus be better able to confront future scientific issues as they affect personal, social, and political decisions. Less altruistic, but no less important or defensible, is the hope that with better understanding of science, public commitment to the support of science will be sustained, if not increased.

As ~~many~~ Some of you know, I am an enthusiastic advocate for the engagement of scientists in K-12 science education and am myself seriously involved in such efforts here in the District of Columbia. But today, I want to stress a different aspect of scientists' efforts to share their enterprise with the public, the one that becomes so evident in talking to school children's parents, or even rather well-educated friends and associates. William Carey, the man we are here to honor, taught us that it is only by constantly raising new, even difficult questions about scientific activities, that we can hope to contribute to the welfare of our nation and the world. I shall try to follow his example.

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Even if we were to succeed beyond our wildest dreams in improving K-12 science education and were to make significant advances in developing fruitful programs for undergraduate liberal education, there would still be a lag of several decades before the newly educated public reached maturity and a degree of influence on public life. During that period, a long array of scientific issues will arise from the frontier and reverberate behind.

The recent past is full of examples in which the disparity between our end-of-century scientific knowledge and the public reception and perception of that information yielded ill-informed and regrettable public policy decisions. Often the final, critical debates left the actual science out of serious consideration. In such a situation, and it is obvious that such ~~situations~~ issues will arise with increasing frequency, it is not unfair for the public to question its investment in frontier research. If it intends to ignore scientific knowledge in trying to deal with important national issues, it could save a lot of money by cutting the frontier off.

It is essential then to ask **why** the public ignores the scientific findings. Many scientists would answer this question by demeaning remarks about the ignorance of the public, and arrogant assertions about popular and honestly held views that are inconsistent with scientific knowledge. Others, more sympathetic and engaged, are truly frustrated upon learning that many people actually believe in the predictive powers of astrology or are unwilling to recognize the fact of biological evolution. Such resistance to scientific findings and ignorance of scientific knowledge is not confined to any particular segment of society. Remember that a few years ago a video made at a Harvard commencement showed us that many of the graduates had no idea why spring and summer on Earth are followed by fall and winter.

Some scientists conclude from such observations that the public is not only poorly informed, but is uninterested in changing, and then wash their hands of responsibility. Other scientists are beginning to realize that scientists themselves bear a large part of the blame for these circumstances. And many scientists are now quite willing to talk with the press, to appear on TV, to write for general periodicals, and publish books for the nonscientific public. In spite of all this activity, however, we are not doing very well. The books for laymen get excellent reviews and a reasonable amount of publicity; but they don't sell many copies. And the blockbusters, like Stephen Hawking's, ~~best sellers~~, sell a lot of copies but remain unread on coffee tables around the world. More often than not scientists fail to communicate, and not for want of trying. The temptation is to blame the general scientific ignorance. But that really won't do, because it is equivalent to giving up. What scientists need to do is to change the way they talk to the public. In the lab, if one experimental approach doesn't work, we try others. We need then to experiment with new ways for communicating.

We can identify some experiments that have already been carried out.

One example is the very recent situation in Great Britain regarding the consumption of beef from cattle that may be diseased by bovine spongiform encephalopathy. There is very circumstantial evidence connecting the eating of meat, that is, muscle, from diseased animals and the incidence of the fatal neurodegenerative Creutzfeldt-

Jakob disease. According to reports in Nature and Science, this relation was offered as the best available explanation for the recent occurrence of 10 cases of an unusual form of C-J in relatively young people in Britain. No data were made available with the government's announcement and none of the new observations had been published in scientific journals. About six years ago, related findings had led to a ban on the use of cattle and sheep offal, tissue such as brain and other enervated parts, even as feed for animals intended for human use, because more compelling data indicat~~ing~~ed that C-J ~~can~~ might be spread by consumption of such animal parts. To a large extent the concerns about meat stem from its possible contamination with nerve tissue.

The British situation demonstrates the difficulties inherent in making public policy in the face of uncertainty. That government's initial reactions were aimed at reassuring the public and restoring confidence, essentially by telling people **not to worry.** Needless to say, fear and panic followed. Britain's top veterinarian called the actions "Hasty, ill-prepared, disproportionate and unscientific" (The Economist, March 30, 1996, page 25). Data were available from a British scientific review committee charged with evaluating the situation, but the data were held back, even at a scheduled European meeting, this adding to the suspicions. As it turned out, none of the available data suggested an epidemic.

The Economist (March 30, 1996, page 17) correctly pointed out: "If the government is to restore its credibility, it must seek chiefly to

**inform**, not to **reassure** by whatever means. The reluctance to do so was presumably based on 'the damage to confidence' that would result from acknowledging, exploring and discussing the risk". As a consequence of the mishandling, millions of people all over the world believe that there is a proven cause and effect relation between eating beef products and dreadful neurological disease. That view was strengthened when, on March 27th, the European Commission confirmed a ban on the international sale of all meat and other products of British cattle, including even milk. Now, it is proposed to slaughter even dairy cows in Britain although there has never been any evidence that milk could be dangerous. Rather than reassuing anyone by its failure to discuss the situation straight-forwardly, the British government fostered panic that came back to haunt it,. But why did the British government hide ignore its own scientific advisors work?? What could the scientists have done that would have been more compelling?

The attitudes of some people toward the 'ozone hole' present another example of failed scientific communication, although there is much less uncertainty about the scientific findings than in the so-called 'mad cow' situation. The role of chlorofluorocarbons (CFCs) in the creation of the atmospheric ozone hole is quite well established. The information is public and widely reported. The influence of dissipated small molecules on the stability of the atmospheric ozone layer was first inferred for nitrogen oxides by Paul Crutzen in 1970. In 1974, Molina and Roland showed that chlorine atoms, which can be released from CFC's upon exposure to ultraviolet light , cause the rapid destruction of ozone. They warned of the possible long term effects well before the ozone hole was even discovered. These data, and the correlation of accumulating atmospheric CFC's with Antarctic ozone disappearance were sufficient to convince 70 nations to agree to eliminate CFC production by 2000. One US Congress actually shortened our national elimination timetable by 5 years. Last year, Crutzen, Molina, and Rowland shared the Nobel Prize for chemistry. Yet, in the same week the prize was announced, another US Congress held hearings to consider delaying the ban on CFC production. Of course, the conclusions reached even by Nobel Laureates may turn out to be wrong, but that was not why Congressional discussion denied the scientific consensus. The scientific conclusion was contrary to the political ends desired by some members of Congress. One reaction to this is to throw up our hands in disgust, and rail against 'politics'. But another would to be ask why the scientific community was less convincing than the political considerations. Was there another way to present the case, one that would have been more successful? Did we start too late? Were we confusing? Were we not persistent enough? The challenge is to find new ways to convey the science so that it is not so easy to ignore.

We've known for a long time that excessive use of antibiotics in clinical medicine and animal husbandry would lead to wide-spread resistance to these drugs. Here, the scientific conclusions were unassailable. Scientists have been in agreement on the dangers, and they spoke out. But they did not have the impact they should have had on policy decisions. Now, many very useful antibiotics are ineffective because of the spread of genes that make bacteria resistant to the drugs. No longer can any of us be confident that simple and inexpensive treatment will cure us or our children of a range of deadly infectious diseases.

The high-energy physics community made an all-out effort to save the super conducting supercollider from the trash bin. They tried everything from a hard-sell, to sharing with the public their vision of the fundamental knowledge to be acquired. Steven Weinberg's marvelous book, *Dreams of a Final Theory*, is a good example. If you have read it, you know that it is probably the best available description for laymen of what twentieth century physics is all about. And ~~he~~ Weinberg is inspiring about the opportunitites in partic~~y~~le physics. But as an argument for the expenditure of billions of dollars of public funds, it fails (and it failed). There is, for one thing, a dissonant resonance in the term "Final Theory"; physicists should have recognized that "Final" enterprises, with a capital F, have had a bad ring since World War II. For another, there is an arrogance of tone that could hardly appeal to the public, or even scientists in other fields, who generally believe that all scientific theories must be provisional.

Then, there is a problem with vocabulary, as in this sentence:

*Any symmetry principle is at the same time a principle of simplicity* (page 138). This occurs shortly after Weinberg introduces the idea of the symmetry of the laws of nature, as opposed to the symmetry of things. Careful reading of Weinberg's explanation indeed clarifies why he considers this to be 'simplicity'. But anyone reading casually or without an ingrained scientific perspective, will surely have been sweating through the preceding pages. They would like to be congratulated for making it through some tough stuff; simplicity will be the last thing they have in mind.

~~The problems continue.~~ According to Weinberg, 'simplicity' is an attribute of beauty and the beauty of a physical theory is, for him (and for many scientists), a major criterion for its evaluation. For instance, he judges Einstein's theory of gravitation as more beautiful than Newton's, and thus more valid, because of its simplicities. As a scientist, I understand this argument. In my own field, I think the double helix is surely beautiful. But I am not the point; will my taxpaying neighbors understand or even think relevant, a beauty they cannot fathom? And how can we expect that the Congress will be able to factor 'beauty' into the political considerations that lead to funding decisions? For some members of Congress, the concept of beauty probably brings the Miss America pageant to mind, not subatomic particles.

Some of the experiments in communicating science to the public have been more successful, for example the efforts of the biomedical community in the past year's budget debates. That success had very little to do with the beauty of modern biology, of which there is plenty, and everything to do with a well-organized lobbying effort and the public's interest in health problems. Scientists worked in many congressional districts with individual Representatives and Senators, to make sure that members of Congress knew about the biomedical research in local institutions, and the jobs and money that federal grants provide to local economies. One can argue, and I do, that the lobbying effort, which concentrated on one field of science to the exclusion of others, was not ideal. But as an example of something that works, and conveys aspects of science to the public, the results speak for themselves.

Many scientists are uncomfortable confronting the obvious fact that the amazing, 40-year long national support for biological research which is embodied in the history of the NIH has its roots in a national desire to improve health care. The essential point, which has been successfully conveyed to the Congress and Executive Branch, is that in order to improve health, it is necessary to deepen our understanding of biological phenomena. Over the years, the NIH's investment in basic research on bacteria, yeast, flies, plants, and worms has been directly applicable to human problems such as cancer, neurological disease, and now even behavior.

Astronomy provides a quite different example of what succeeds in capturing interest and support for science. This is surely a science with a minimum of obvious practical implications. But it does capture people's imagination. There is an object lesson in cosmologists' ability to explain their science in an inspiring way, a lesson which has eluded high-energy physicists. Discoveries in astronomy, particularly when coupled with an adventure in space, as provided by the Hubble Space Telescope, are avidly reported and followed. Moreover, almost uniquely in the scientific community, astronomers have been willing to debate and then state their priorities. Remarkably, both public and private monies have continued to flow. The funds are now secure for the Gemini project, two national 8-meter telescopes, one each in the northern and southern hemispheres. It is true that this is at the expense of several smaller, older, national telescopes, but it is probably that these will be purchased by private and state institutions---at bargain prices----and continue to operate. At the same time, privately funded new telescopes are going up at an exciting pace: the two 10-meter telescopes funded largely by the Keck Foundation for CalTech and the University of California, have a public component in the investment by NASA on behalf of astronomers nationwide; the Magellan Project for two 6.5-meter telescopes at the Carnegie Institution's Las Campanas Observatory in Chile is proceeding as a consortium of private and state institutions; the Sloan Foundation has provided the wherewithal for a consortium to build a special galaxy survey telescope. The cost of all of these together is small in comparison to that of the now defunct superconducting supercollider, but the difference in public interest has to be a component in the different outcomes.

A few years ago, as a consequence of public pressure from the community of breast cancer patients, substantial sums were set aside for research in breast cancer. Outspoken and distinguished scientists criticized this targeted expenditure as detracting resources from more fundamental work likely to enhance, more efficiently, they believed understanding of all cancer. But these negative reactions overlooked the stimulus and support for science that a real human need can give to fundamental work. In the last year, two genes which, when mutated, are associated wit h breast cancer have been identified. One of them, BRCA-1, has a role in both inherited and acquired breast and ovarian cancer. It has turned out to be a new kind of oncogene and thus has advanced fundamental understanding, and it provides an important tool for determining risk and perhaps even therapeutic approaches. There will be similar important scientific advances from increasing biomedical research emphasis, demanded by the public, on women's health problems.

One final experiment. Tom Lovejoy, a biologist who is the advisor on environmental issues to the Secretary of the Smithsonian Institution has, for some years now, been shepherding any government official who would go, including senators and representatives and cabinet members, on trips to the Amazon. They return with a new understanding and commitment to the preservation of tropical rain forests in particular, and the environment in general. The latest evidence for Lovejoy's success was in yesterday's news stories: Secretary of State Warren Christopher now counts environmental concerns among national security issues. (Wirth - Real men don't do environment)

Daniel Kevles, Professor of the History of Science at CalTech says, in a recent paper, that too often, scientists fail to make the case for science (Princeton Symposium reference). He offers some advice about how to improve. Thus, he suggests that we eschew the hard sell ~~for a statement~~ of visions, that instead we evangelize in the spirit of an adventurous frontier that has always appealed to American independence of spirit and fundamental pragmatism. He says that science has lost its nerve. for vision.

But I worry that there has been a national loss of nerve, and that evangelizing, by itself, will today fall on deaf ears.

Kevles, however, gives us some additional hints, which, together with a strong vision, might help us to develop new ways to communicate with the public. He reviews public support of science beginning in about the middle of the 19th century, Importantly, he points out that regardless of the spin put on it by scientists, Americans have understood and supported science in the past, with both public and private funds, primarily because they expected practical benefits. His story also describes a fickle political process. Apparent trends in funding and support for science were often short-lived. And although there were dramatic changes from one Congress to another, over the decades, American science flourished.

There are additional hints about what might work and what might not, in the experiments I reviewed. Kevles' idea that the promise of practical benefits is important, is supported by the experience with the NIH budget. Besides advances in disease diagnosis and treatment, NIH research yielded up a completely new major industry, biotechnology. But practical benefits can't be the whole story. A direct relation to everyday experience is another important element. Everyone has seen the stars, and the moon, and probably even other planets, although they may not have realized how easy it is to see Venus and Jupiter. Anyone who has looked at the sky has wondered about the nature of the universe. Astronomy may be a sophisticated science, but its subject is in everyone's experience. Some things are of course not part of everyday experience, but they could be. No book, and no talk can match the experience a nonscientist gets if she or he is invited into a lab, to see what's there, to ask questions, to see real people working at real stuff. Why don't we invite the public in more often....like Lovejoy invites people to the Amazon.

Still, there are times when talk is the only way to communicate. We need to learn to do it effectively. Many scientists have had the experience of giving a lecture for a general audience. And some of those scientists are brilliant to listen to. Members of the audience congratulate the speaker at the end, and say how marvelous the talk was. And then, they often add, 'of course, I didn't understand anything you said, but it was wonderful'. Dazzling people is not the same as communicating. It is helpful to start with something from everyday experience to begin with. And it is helpful to convey the context in which particular research falls and from which it gains significance. Often we speak of what interests us, but not what interests the listeners. Often we only begin speaking when a crisis looms; our efforts at communicating should be continual. Often we think that national exposure on television or major newspapers is what matters most; but efforts in cities and towns all over the country will bring science home to the people who count. We can talk about how science has promoted local industry, and along the way get the science across. We can talk about how science has allowed modern communication, transportation, even the things that are on the supermarket shelves. Very few people have any idea that our whole modern life is based on scientific advances.

Another thing we could do is to stop speaking with certainty about uncertain things. Scientists do not do that among themselves; it is both disrespectful and dumb to do it when speaking to nonscientists. True, the idea of probabilities is not broadly understood. But it could be, if we spoke of it and made the effort to explain. If the public does not understand probability and thus risk, it is our job to teach, not to wring our hands over public ignorance. This is especially pertinent when issues of health and safety and environmental degradation are at issue. — like with the mad cow disease.

Bill Carey once wrote (Science Magazine, 219 p 911, 1983) of the "surpassing importance of trust, in the contract between science and government in an open society".

In the face of uncertainty, we have to be honest and outspoken. Too many people have experienced science only in classes that are dogmatic about science, and present it as a body of unassailable facts. We know better. Everyone should. When the pertinent available scientific facts are insufficient to support a firm conclusion and policy **must** nevertheless be made, we should stop presenting opposing views as either/or options and stop waffling about holes in scientific knowledge. We should point out that substantial scientific disagreements indicate uncertainty and that in the end, neither view may be correct, or perhaps even both will be. We should not permit political pressures to back us into scientifically indefensible corners.

Still, there are some challenges that really seem impossible. We have very difficult problems when a scientific conclusion is relatively firm, but is contrary to desired political ends. What can we do to make the scientific conclusion the desired political end? Rather than slinking off disgruntled, **that** should become the challenge. Otherwise, we are acquiesing in the continuation of a process that leads to irrational public policy. We have to begin to think that it is our fault, not **theirs**, whoever **they** may be. In politics, there is always a spectrum of views. We should work with those who oppose a scientifically bad policy. Rather than worrying about the effects of such opposition on our own funding, we should speak out whenever wrongheaded ideas are headed for success. *(A recent examples is the funding of research on Alternative Medicine)*

Another issue that seems to have few solutions comes from the perception that science is a challenge to religion. It is a testimony to human curiosity, the driving force behind science, that from the earliest recorded times, people wanted explanations for the amazing natural phenomena they experienced. In the absence of real understanding, they made up answers. Many of these depended on supernatural elements and these, entwined with codifications of approved behavior, and the lives of inspiring leaders, developed into the great religions. Later, when scientific explanations began to emerge and challenge the myths, trouble began. And trouble continues as each major scientific advance challenges the supernatural explanations and also diminishes the special position assigned to humans by religious systems. So two centuries after geologists like Hutton and Lyell recognized just how ancient our planet might be, and more than a century after Darwin and Wallace showed us how we could understand the history of life on Earth, we are still arguing about teaching these facts to school children in the U.S. And while this is fueled by loud but relatively small fundamentalist religious groups, polls and personal experience tell us that a lot of thoughtful and intelligent people are loathe to give up the comforting religious creation myths for the chaos implied by natural explanations. Can we learn how to respond ~~to such people~~ constructively?

Conflicts between religious ideas and modern science raise profoundly difficult questions. Many scientists are tempted either to ignore religious sensibilities or worse, dismiss them ~~arrogantly~~. But they will not go away readily. They must be taken seriously because they are strongly felt by decent people. Respectful, informative responses are needed, if science is to retain the public's support. Denial is never constructive. There is some wisdom in the public inclination to move cautiously when social assumptions that have worked productively for millennia are being challenged. For instance, modern genetics poses some tough societal issues. They need to be thoroughly and widely discussed before we can find reasonable and acceptable ways to apply the new science for the benefit of all.

Events last year illustrate some of the problems. A coalition of religious leaders, encouraged if not recruited by Jeremy Rifkin, announced a campaign opposing the patenting of human genes, cells, organs, and genetically modified organisms on the grounds that they are creations of God and not inventions of man. It is true that genes, cells and organs are not inventions of man---or of woman either; but genes and organisms modified by modern techniques or classical cross-breeding are, in at least some sense, inventions of humans. There are of course legitimate questions about some of the DNA sequence patenting that is going on, but the idea that DNA is holy doesn't make sense to most scientists. Once you have synthesized a gene in the lab, and have recognized that the genes of humans and yeast cells can be interchangeable, it is impossible to think that DNA, human or otherwise, has some special aura. Contrary to the frequent headlines, scientists are not 'playing God" when they manipulate DNA; they are being quintessentially human in their desire to understand nature. Why can't we get this idea across? It would help some if scientists stopped using the word "God" in the titles of their books. How does it serve real communication about science to say, as one astrophysicist did in describing the COBE satellite data on perurbations in the microwave background radiation as 'traces from the mind of God"?

If we are to improve the communication of science to those behind the frontier, the scientific community probably needs to recapture access to the public. Public information about science is now, to a large extent, in the hands of institutional public relations departments, the science policy establishment...that is, yourselves, and the media. We need a more direct line. We need to show that we are real, actually quite ordinary people. Perhaps we could even avoid the tendency, apparent even in the scientific press, to present everything in an adversarial mode; the public is certainly engaged by conflict., but people are also engaged by their self-interest, and that is always served by straight-forward information.

If we can get a direct line, we will probably have to clean up our act. Too often these days, when scientists **are** given an opportunity to speak about their work, they are more interested in advancing the cause of their next grant, or their company's financial status, than in conveying information to the public in a meaningful way. There is too much hype. Every gene that is discovered will lead to a cure for some disease.......maybe, but not for a **long** time. Even the superconducting super collider was said to have important implications for improving human health.

We have not used well our wits and talents to convey the extraordinary scientific enterprise and the amazing things we have learned about the world. The ignorance behind the frontier is our responsibility as scientists; no one will know what we are doing if we don't find ways to tell them, ways that can be heard because they connect to the everyday world in which people live.

Some months ago, the New York Times Magazine ran a photo essay highlighting outstanding women in all the fields that contribute importantly to our nation's welfare. There was not one scientist in the group. The same thing often happens when men are listed for similarly important contributions. Scientists are left out of the reckoning. We can change that if we find new ways to talk about science, ways to talk so we are heard, and listened to.